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Corrosion Behavior of Welded Joints for Cargo Oil Tanks of Crude Oil Carrier

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Abstract: E32 grade corrosion resistant steel was welded with welding wires with three different S contents. The microstructure, mechanical properties, inclusions, and corrosion behavior of welded joint were investigated. The joint coupon corrosion test and potentiodynamic polarization test were carried out under the simulated corrosion environment of the inner bottom plates of cargo oil tanks. The pitting initiation and propagation mechanism of the weld metal were studied by scanning electron microscopy and infinite focus. The results indicated that the microstructures of three kinds of weld metals are all composed of acicular ferrite, ferrite side-plate and proeutectoid ferrite. The microstructure of heat-affected zone is composed predominantly of bainite. Joint welded with low S filler wire has good mechanical properties. S can decrease free corrosion potential and increase the corrosion tendency. The pitting initiation is oxide inclusion or sulfide-oxide inclusion complex. S can induce the formation of occluded area and promote the corrosion propagation. The chemical compositions of weld metal is similar to base metal, which can limit the galvanic corrosion between weld metal and base metal, and avoid formation of corrosion step.

Key words: cargo oil tank; welded joint; pit corrosion; corrosion step

The inner bottom plates of cargo oil tanks serve in a special corrosion environment. There is an oil film on the inner bottom plates, which can protect it from corrosion. Stagnant water with a high NaCl content of about 10 mass% may exist between the oil film and crude oil in cargo oil tanks. The local oil film may be damaged during oil tank washing, resulting in direct contact of stagnant water with bare steel plate and leading to pit corrosion on steel plate. For conventional ship steel plate, the growth rate of pit corrosion is about 2—4 mm/a, which is serious damage for crude oil tanks[1]. A newly developed steel shows good corrosion resistance, with its pit corrosion growth rate suppressed to 1/4 as compared with that of conventional steel[2]. However, the corrosion behavior of welded joint of the newly developed steel is not extensively studied. The joint suffers not only pit corrosion but also galvanic corrosion. To ensure the safety of cargo oil tanks, it is necessary to study the corrosion behavior of welded joint of the inner bottom plate.

The study of corrosion behavior of low alloy steel welded joint in chlorine ion environment focuses on two problems. One is pit corrosion, which initiates from inclusion and propagates at the effect of self-catalytic acidification action[3-5]. Another is corrosion step on the interface of joint[6-8]. Weld metal and base metal may form a galvanic couple because of their composition and microstructure differences, resulting in galvanic effect which may accelerate corrosion.

In this study, the corrosion resistant steel which satisfies the specification of E32 grade is welded with three kinds of welding wires containing different S contents. Microstructures, mechanical properties, inclusions and corrosion behaviors of the joints were discussed.

1 Experimental Materials and Procedure

E32 grade steel with corrosion rate of about 0.7 mm/a, which is much smaller than the corrosion rate of 5 mm/a of conventional steel and satisfies standard of international maritime organization (IMO), was used

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as base metal for welding. Each joint specimen was welded with two steel plates of the sizes of 500 mm×200 mm×20 mm and the groove shape is shown in Fig. 1. Gas metal arc welding (GMAW) with 100% CO_2 as shielding gas was used. The flow rate of shielding gas was 20 L/min. Heat input was 19 kJ/cm, and interpass temperature was lower than 150 ℃. Three kinds of welding wires with diameter of 1.2 mm and different S contents were used for welding. No. 1 wire is a newly developed corrosion resistant welding wire, No. 2 wire is conventional welding wire, and No. 3 wire contains high S for comparison. Chemical compositions of weld metals are shown in Table 1. The mechanical properties of welded joints are shown in Table 2, which are good and satisfy the standard of international association of classification society.

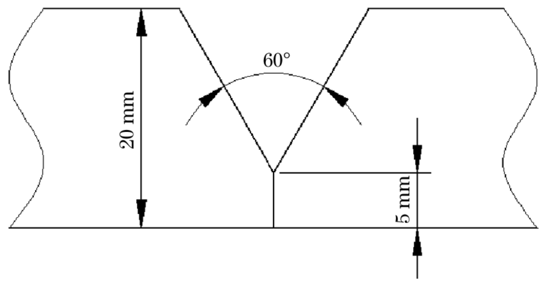

Fig. 1 Schematic diagram of welding groove

Table 1 Chemical compositions of weld metal mass%

Wire No.	C	Si	Mn	S	P	Ni	Fe
1 (Low S)	0.06	0.3	1.1	0.002	≤0.02	0.6	Balance
2 (Medium S)	0.05	0.4	1.4	0.005	≤0.02	0.1	Balance
3 (High S)	0.05	0.3	1.3	0.008	≤0.02	1.0	Balance

Table 2 Mechanical properties of welded joints

No.	$A_{kv-20\,℃}$/J			Joint transverse tension		Side bending
	Notch position at weld metal	Notch position at fusion line	Notch position at fusion line +2 mm	R_m/MPa	Fracture position	$D=3a$
1	108	180	300	480	Base metal	Perfect
2	99	179	—	475	Base metal	Perfect
3	87	153	—	480	Base metal	Perfect

Note: $A_{kv-20\,℃}$—Charpy impact energy; R_m—Tensile strength; D—Diameter of the former; a—Thickness of test specimen.

Specimens were ground, polished, and then etched with a 3 vol.% nital solution. The microstructure was observed and photographed with Leica MEF-4M optical microscope (OM) and S-4300 scanning electronic microscope (SEM).

Joint corrosion tests simulating inner bottom environment of cargo oil tank (COT) were carried out according to the corrosion resistant steel standard approved by IMO. Potentiodynamic polarization tests were conducted for weld metals and base metal. The joints were corrosion tested for 168 h. The size of each test piece is 25 mm×60 mm×5 mm. Test solution is 10 mass% NaCl with the pH of 0.85, which is adjusted by HCl solution. The temperature of the test solution is (30±2) ℃. The simulating corrosion test apparatus for inner bottom plate is shown in Fig. 2. Corrosion appearance was observed with SEM and height variation from weld metal to base material was measured with infinite focus.

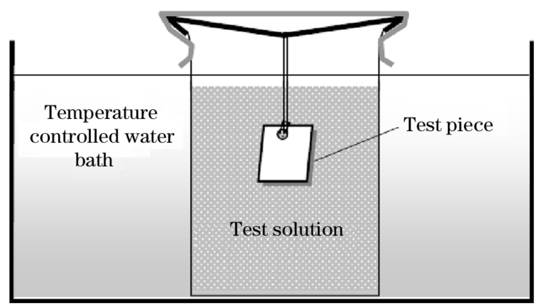

Fig. 2 Apparatus for simulating corrosion test of inner bottom plate

2 Results and Discussion

2.1 Microstructure

Microstructure photographs of weld metal and heat-affected zone are shown in Fig. 3, where the fusion lines are denoted by white arrows. The microstructure of weld metal consists of acicular ferrite predominantly, ferrite side-plate and proeutectoid ferrite, and the microstructure of high temperature heat-affected zone consists mainly of bainite.

2.2 Inclusion analysis

The shapes of most of the inclusions in weld metals are spherical, as shown in Fig. 4(a). The size distributions of inclusions in three weld metals are similar. Most inclusions are smaller than 1.2 μm in diameter, while a few inclusions are larger than 2.0 μm, as shown in Fig. 4(b). Most inclusions in weld metals are oxide for all the 3 weld metals, while some sulfide-oxide inclusion complexes appear for weld metals with high S and middle S contents, as shown in Fig. 5.